THE APPLICATION OF LIGHTNING DETECTION AND WARNING SYSTEMS WITHIN THE EXPLOSIVES SAFETY ENVIRONMENT

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ABSTRACT

Lightning has always posed a serious threat to the manufacture, transport, storage and handling of explosives. In recent years, technological progress and advancements in communications systems have increased the availability of various types of lightning detection and warning systems for use within the explosives community.

The use of these systems, which detect the presence of, or potential for, cloud-to-ground lightning, is exposing personnel to one of the most complex elements of atmospheric physics. Armed with this "scientific data", engineers and managers are expected to make the right decision all of the time, decisions that have a significant impact on personnel safety, productivity, and the material and operational readiness of a command. It is a fact of life that the data they are dealing with is not perfect, can be misinterpreted, and in many cases can cause false alarms, which can undermine user confidence in the system and slow response/reaction to future warnings.

The intent of this paper is to make the reader aware of technologies in the realm of lightning detection and system application to the every day operation of the explosives arena. In addition, an objective approach in developing a generic baseline for readiness and warning procedures is offered.

1.0 Introduction

The enormous amount of time, effort and funds expended in implementing lightning protection actions within the manufacturing and storage arenas is an essential part of a common goal, which is the safeguarding of ordnance, people and facilities.

In most cases, protection is primarily orientated toward survivability of the ordnance and the material condition of the facilities in which the explosive material is manufactured and/or stored. However, when considering the purpose for which the ordnance is intended, and the processes involved in the manufacturing and delivery of the material, the need for lightning detection and warning should be given a priority equal to that which is given protection efforts.

As is well known, the mission of the Department of Defense (DOD) is to safeguard our country's interests, support and/or assert foreign policy. This mission places the DOD in only one of two positions at any one time. That is, war or preparation for war.

Whether the requirement for ordnance are from a ship about to withdraw United States civilians from a troubled country or from an artillery unit about to conduct a readiness and training exercise, it is important that the goods be delivered intact and in a timely manner. If an accident occurs, the DOD not only looses expensive and hard to replace resources, both manpower and material, but it must also deal with a significant leadtime in effecting their respective replacements. Meanwhile, a the warfighting ability of a combat unit is degraded. In addition to the material loss, we all too frequently loose valuable, highly skilled and experienced people who are hard to replace. While not ignoring the emotional issues that accompany such a loss, it is important to keep in mind that it is very time consuming to train replacements.

Today we are at peace, for the most part, and as history has shown time and time again, with peace comes budget reductions. What is happening within our present day political and military environment is not a new wave of policy. As in the past, it will take large amounts of money, perseverance, and strong management to sustain the DOD so it can adequately serve as a deterrent to foreign powers, and quickly respond to a threat if one arises.

It is a fact of life that during the transport, loading, manufacturing and unloading of explosives, the specter of danger is more critical than at any other

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time. This is when people are directly involved in a hands-on manner. During such evolutions important management decisions must be made that will have an impact on productivity, mission accomplishment and personnel safety.

In the past, common sense and in many cases a "lets play it safe" attitude, has been the rule of thumb. In the majority of cases the job was done. However, in an environment of limited material and personnel resources, increased operating costs and occasional pressure from management, there is strong potential for people to take risks or to be less attentive to detail for the sake of getting the job done quickly. While some people may dispute this claim, they may want to check with their service's safety center and see how many vehicle, ship and aircraft accidents have identified "get-home-itis", "meet schedule", or "lack of attention to detail" as significant contributing factors.

The intent of this paper is to make the reader aware of technologies in the realm of lightning detection and system applications in the every day operations of the explosives arena.

2.0 Understanding Thunderstorms and Lightning

Prior to discussing lightning detection technology, it is important that the reader gain a basic understanding of, and respect for, lightning phenomena and the threat it poses.

Generally speaking, when identifying people with lightning, there are two groups. The first group consists of people who either fear lightning or ignore it. It is estimated that this group represents up to 80% of the people whose work is directly affected by lightning. The second group consists of people who accept the phenomena as a fact of life and through their understanding of it, react to its presence in a flexible and effective manner.

In the following paragraphs we will attempt to help the first group reader better understand what thunderstorms and lightning are all about. Regarding the second group, the information will provide a different perspective and expose them to some new theories about thunderstorms and lightning. As previously stated, the overall goal is to increase the reader's knowledge of the subject so their ability to orchestrate a flexible and effective response to the threat is enhanced.

2.1 Thunderstorm Origins

The most realistic method of categorizing thunderstorms is to label them as either Synoptic or Air Mass. Synoptic thunderstorms are those which are directly or indirectly generated by major storms or weather systems such as fronts, low pressure systems, and tropical cyclones (hurricanes and tropical storms). On the other hand, air mass thunderstorms are most commonly seen as individual or groups of cells that form in the summertime throughout the 50 states.

2.2 Synoptic Thunderstorms

These thunderstorms usually involve a broad area and demonstrate some consistency as to their movement and intensity. Some storms may be embedded in large areas of cloudiness, as with a warm front, while others will form a distinct line as seen with the typical cold front or with feeder bands spiraling around a hurricane.

In most cases, the most intense synoptic thunderstorm is the type associated with squall lines that are spawned by fast moving cold fronts. These squall lines develop anywhere from 150 to 300 miles in advance of the front, and the thunderstorms associated with them move very rapidly (35 to 60 knots). In some cases, the tops of these storms may extend 10 miles into the atmosphere.

Usually, these types of storms produce severe weather such as wind speeds in excess of 50 knots, large hail, tornadic activity and frequent lightning. One advantage, when dealing with this type of thunderstorm, is that it can be predicted with a high level of accuracy. This capability provides people with a reasonable amount of leadtime to take precautions to reduce the level of avoidable damage, and plan for its consequences, prior to the arrival of the severe weather.

The National Weather Service (NWS) and most services of the DOD have policies that address severe thunderstorms as a singular threat.

2.3 Air Mass Thunderstorms

As noted above, these will normally be generated by the heat of the day and involve either individual or groups of cells. When addressing a group of cells, the most common types are clusters or lines. A good example of a cluster is the large area of activity that develops over the Ocala Forest in North Central Florida. On the other hand, good examples of the line type can be seen along the sea-breeze boundary of the Gulf Coast and in the Southwest U.S. and the piedmont area of the Carolinas where mountains are present.

Under normal conditions, there is a high measure of predictability regarding air mass storms. In most

cases, the only day to day change that may take place is their direction of movement, which is affected by the wind field in the upper atmosphere, or the exact location where they form.

There are times when conditions over a certain area are enhanced by converging wind fields or systems in the upper atmosphere. When this occurs, the storms tend to be more extensive in the area they affect and at times take on a very violent character. The biggest problem with this type of storms, in relation to the explosives arena, is the fact that they can develop rather quickly within a sensitive area and produce a first strike hazard with little or no advance warning. In some cases, overhead development of the storms is common, especially if large concrete or forested areas are present.

2.4 The Basic Elements

To have a thunderstorm, you must have a lifting action, moisture and hydroscopic-nuclei. The lifting action may be caused by heated air rising from the surface of the earth, while the source of moisture may be from an ocean, lake or be present in the upper atmosphere. Hydroscopic-nuclei is the critical element since the water droplets must have something to which they can attach themselves. Common nuclei are salt particles, sand, industrial airborne wastes and volcanic ash.

In most cases when dealing with synoptic thunderstorms, the necessary elements are readily present. However, in the case of an air mass situation, many thunderstorms never mature. This is caused by the absence of sufficient moisture or a strong low level wind field that shears the cell apart and cuts off or distorts the lifting mechanism.

2.5 Stages of a Thunderstorm

A typical thunderstorm involves three stages; 1) Cumulus, 2) Mature, and 3) Dissipation. In most cases, the time it takes a thunderstorm to complete all three stages is less than two (2) hours. The reader must keep in mind that with the exception of the cumulus stage, the stages of a storm will normally have no direct relation to its severity or the amount and type of lightning it will produce. For convenience, the term "cell" will be frequently used to address individual thunderstorms.

2.5.1 Cumulus Stage

This stage is recognizable by the puffy white clouds that form. The cell feeds on the warm moist air from below, but as it builds into the atmosphere, it also begins to draw energy from the surrounding air.

During the cumulus stage, all currents within the cell are upward and as the cell builds further into the atmosphere, some downdrafts begin to form in the higher portion of the cloud, which is normally above the freezing level. If the elements sustaining the cell persist, then it will continue to grow. However, if any one of the elements is weakened, the cell will release its moisture and be classified as only a rainshower.

2.5.2 Mature Stage

During this stage well defined downdrafts begin to develop within the cell. This action further increases the vertical development of the cell. As the cell continues to grow, an anvil will gradually develop (normally above 23,000 feet), the cloud mass takes on a more ominous character as its moisture content increases, and lightning begins. By definition, a cell is considered to have fully matured when precipitation falls from the base and reaches the ground. Prior to the onset of rain, a first gust front signals the release of the cold dry air that has developed within the cell.

This primary downdraft travels outward in all directions from the cell and is at its greatest extent along the cell's axis of movement. The first gust front will normally extend 15 miles ahead of the cell and as far as 5 miles in other directions. Wind speeds in excess of 100 knots have been recorded with these first gust fronts.

Most people are familiar with the change in wind direction and speed, and the rapid cooling associated with this event. It is also important to note that at this time there is a significant increase in lightning activity. Once a cell has matured, it will not develop any further.

2.5.3 Dissipation Stage

During this stage all motion within the cell is downward. Lightning is still active during the early part of this stage; however, as the rain subsides, the lightning will taper off and the wind will gradually abate. At this point many people will disagree that they have frequently encountered situations where the wind, lightning and rain have persisted for many hours from one cell. To take the reader one step further and also address this issue, lets take a look at a fourth stage of the thunderstorm.

2.5.4 Re-Development Cycle

As mentioned in the discussion of the mature stage, there is a release of cold air from the cell. While this air travels outward from the mother cell it is warmed and picks up moisture. In addition, by its motion, contact with the ground and the heating that takes

place, it begins to rise and turn in a cyclonic (counter-clockwise) trajectory and thus has strong potential of developing into a new cell. This re-development cycle is most common with synoptic thunderstorms, but is not uncommon in an air mass situation.

These new cells will usually develop ahead of or slightly behind the mother cell. In most cases people will not be able to differentiate the new cells from the old ones because they will frequently become embedded within the residual cloud mass generated by the old cell. While the NWS has the advantage of modern weather radars to detect this cycle, a good thumb rule for the layman is that if during the dissipation a secondary area of strong winds is encountered, then it should be assumed that a new cycle is in progress.

2.6 Thunderstorm Categories

The NWS only addresses two categories; Thunderstorms and Severe Thunderstorms. By definition a severe thunderstorm must produce wind gusts of 50 knots or greater, and hail if present, that is 3/4-inch in diameter or greater. If conditions are less than these, then the system is just classified as a thunderstorm. In some cases wind damage can be used to classify a storm as severe.

It is also important to note that lightning frequency and flash flooding are not criteria for severe thunderstorms. While tornadoes are normally associated with severe thunderstorms, they are treated as a separate issue when it comes to issuing warnings or watches.

2.7 The Lightning Profile

The atmosphere in its normal state has a positive charge, while the earth holds a negative one. The presence of a thunderstorm will induce a mixture of charges within the cell, while the surface under and around the cell will gradually assume a positive charge. Further, an increase in the potential charge in the electrical field between the earth's surface and the thunderstorm cloud mass will also take place. For the most part, lightning activity takes place during the mature and dissipation stages of the thunderstorm. Since the most dangerous form of lightning is the cloud-to-ground discharge, a detailed discussion on the processes involved in this phenomena is provided.

A cloud-to-ground lightning discharge is made up of one or more intermittent partial discharges. The total discharge whose time duration is of the order of 0.5 seconds, is called a flash; each component discharge, whose luminous phase is measured in tenths of milliseconds, is called a stroke. There are usually three or four strokes per flash, the strokes being separated by tens of milliseconds. Often lightning as observed by the eye appears to flicker. In these cases the eye distinguishes the individual strokes which make up a flash.

Each lightning stroke begins with a weakly luminous predischarge, the leader process, which propagates from cloud-to-ground and which is followed immediately by a very luminous return stroke which propagates from ground-to-cloud. It has been found that the electrostatic field takes about seven (7) seconds to recover to its predischarge value after the occurrence of a lightning flash at a distance beyond 5 Km, but when the flash is very near, the recovery time may be different due to the presence of space charge. In both cases, regeneration of the field takes place exponentially.

2.7.1 Stepped Leader

The usual cloud-to-ground discharge probably begins as a local discharge between the positive charged region in the cloud base and the negatively charged region above it. This discharge frees electrons in the negative region which were previously immobilized by attachment to water or ice particles. The free electrons overrun the positive region, neutralizing its small positive charge, and then continue their trip toward the ground, which takes about 20 milliseconds (msec). The vehicle for moving the negative charge to earth is the stepped leader which moves from cloud-to-ground in rapid luminous steps that are about 50 meters in length. Each leader step occurs in less than a microsecond, and the time between steps is about 50 microseconds.

2.7.2 Return Stroke

When the stepped leader is near ground, its relatively large negative charge induces large amounts of positive charge on the earth beneath it and especially on objects projecting above the earth's surface. Since opposite charges attract each other, the large positive charge attempts to join the large negative charge, and in doing so initiates upward-going discharges. One of these upward-going discharges contacts the downward-moving leader and thereby determines the lightning strike point.

When the leader is attached to ground, negative charges at the bottom of the channel move violently to ground, causing large currents to flow at ground and causing the channel near ground to become very luminous. The channel luminosity propagates continuously up the channel and out the channel branches at a velocity somewhere between 1/2 and

1/10th the speed of light. The trip between ground and cloud takes about 100 microseconds. When the leader initially touches ground, electrons flow to ground from the channel base and as the return stroke moves upward, large numbers of electrons flow at greater and greater heights. Electrons at all points in the channel always move downward, even though the direction of high current and high luminosity moves upward.

It is the return stroke that produces the bright, visible channel. The eye is not fast enough to resolve the propagation of the return stroke, or the stepped leader preceding it, and it seems as if all points on the channel become bright simultaneously.

After the first return stroke is complete, more charge may be made available to the top of the ionized channel and a dart leader will then pass down this branchless channel to the ground, once more depositing negative charge. A second return stroke then passes up the channel. The process may continue several times in a fraction of a second.

2.7.3 Bolts From The Blue

In a reverse pattern we can view the anvil and its positive charge which extends over a section of earth where the ground is still in a state of negative charge. It is not unusual for the anvil to have a base 25,000-30,000 feet above ground level. When considering the distance involved, it is not unusual to see strong discharges with this type of lightning. These cloud to ground strokes are frequently called "Bolts from the blue", since in some cases they will strike in a clear area many miles from the cell. There have been reports of these lightning strokes occurring up to 30 miles away from the main cell, and producing voltages in excess of 150K/amps.

During the dissipation stage the anvil will gradually disperse and break away from the main cell and therefore, will loose its ability to produce lightning. It must be remembered that if a redevelopment cycle is in progress, the lightning will also run in a cycle with little or no noticeable break in activity.

3.0 Detection and Warning Technologies

3.1 Principals of Operation

A TOA Lightning Position and Tracking System network consists of three to six receivers each, connected by a dedicated full duplex terrestrial data link to a central analyzer (CA) (Fig. 1). At each antenna site, there are two simple whip antennas (1.2 to 5.0 meters in height). One antenna receives LORAN-C signals, while the second monitors the electric field. These have no special siting requirements, and can be placed in the vicinity of metal objects, other conductors, or atop conventional buildings. No alignment checks or frequent periodic maintenance is necessary.

The electronics at each site include a lightning strike detector and a timing signal generator synchronized to within a few hundred nanoseconds of the output of the timing signal generator at each of the other respective locations. Electric field measurements in the 2 to 500 KHz range are sampled continuously. A very specific wave form is associated with the lightning return stroke. The electromagnetic pulse emitted by the strike is assumed to originate at a point perhaps 100 meters above the attach point to the earth's surface. The timing of the peak of the wave form is ascertained within a few hundred nanoseconds.

A minimum of three stations must detect the strike in order for a location to be calculated. For a three station solution, the central analyzer solves the complex spherical hyperbolic explicit non-interactive equations necessary for stroke location. The data is output in latitude and longitude coordinates. Custom built ARSI hardware allows for extremely fast hardware trigonometric calculations, as a software approach would not allow the multiple return stroke location ability that is an LPATS characteristic. LPATS can monitor the individual return strokes in a multiple lightning flash only 15 milliseconds apart, discriminating more than 50 strikes per second (a rate unlikely to be approached in nature).

For the operational location of lightning cloud-to-ground strokes, there are essentially two acceptable approaches: 1) magnetic direction finding (MDF) [1], and 2) time-of-arrival (TOA) [2]. The MDF technique has been in widespread operational use since the late 1970s. While it certainly represents a major advancement over the highly limited lightning detection capabilities of past systems, MDF systems are subject to problems of site errors due to 1) maintaining exact antenna orientation, and 2) the presence of metal in buildings, buried cables, and other similar obstacles [3] Darveniza and Uman, 1983. As noted by Pierce [4].

A time-of-arrival (TOA) method is by far the most accurate way of fixing the source of an individual spheric. It is also, understandably, the most elaborate and expensive. TOA systems are less subject to errors than are cross-loop techniques. Polarization errors are effectively non-existent; site errors are very small. However, if the potential accuracy of the TOA system is to be realized and confusion between separate atmospherics is to be avoided, interstation

timing of approximately 10 microseconds is required. This implies the installation of accurate time standards at each station."

Since these assessments were made, there has been a dramatic revolution in microelectronics, resulting in the availability of low cost receivers for easily available timing signals (such as LORAN-C), obviating the need for such expensive timing sources as atomic clocks. A four station prototype TOA network was designed by Atlantic Scientific Corporation and established over the Florida peninsula in the spring of 1982. Earlier papers by Bent, [2] [5] and Lyons and Bent [6] has described the basic system operations and presented initial examples of data collected by operating networks covering the U.S.

This paper will summarize the techniques that are currently being employed to display and interact with this newly available data base, as well as present representative case studies obtained from operational networks. At this time, there are many on-line users for LPATS data including television and radio stations, utilities, military bases, and industrial facilities.

3.2 Reported Results (TOA)

Theoretical accuracy analysis and academic discussion of error sources are interesting, but the bottom line is actual, demonstrated performance. In this section, we present data captured from an operating system which will add credibility to the claims and analysis of highly accurate lightning stroke positional data.

The major problem with trying to assess the accuracy performance of any lightning tracking system is the absence of absolute ground truth data. ARSI has wrestled with this problem for years, and the outcome of any LPATS vs. actual assessment effort could be challenged to some degree because of shortcomings in the reference data (i.e., ground observer judgements, inadequate statistics, etc.).

One of the best techniques has proven to be the comparison of fixes from two independent, differently located networks. Good fix agreement generally must mean that both networks are highly accurate, but disagreements convey no information as to which net is inaccurate or why. This technique is also really useful only when both nets cover the same area with the same degree of theoretical accuracy and detection efficiency, which is a rare situation.

Fortunately, a method has been reported by one LPATS customer that is elegant in its simplicity and also extremely difficult to take issue with Dr. M.J.G. Janssen has recently reported [7] on the performance of the Dutch system owned and operated by KEMA (the Dutch power utility). His method was based on the fact that a high object will have a large attractive radius, and if the lightning fix data base is examined in the area around such and object, there should be an obvious concentration of fixes. Knowing the true latitude/ longitude of the object and comparing against the centroid of the fix concentration then should give a measure of the mean system accuracy in that location. Not only does this technique expose systematic (mean) error, but the spread in the fix concentration gives an indication of the random error.

Figure 5 is extracted from Dr. Janssen's paper. The distribution of strokes grouped into 100-meter x 100-meter bins is shown relative to a 300-meter tall tower. The average error is on the order of 300-meters, with no clean distinction between random and systematic components. This compares very favorably with the best-case accuracy of about 200-meters predicted in Figure 6 for random error only. Of course, Figure 6 is not the Dutch network, but the 200-meter figure represents about the best average figure than can be expected from a TOA network regardless of configuration. Note the obvious absence of strokes at larger radii from the tower.

Intrigued by this method of assessing accuracy, ARSI performed a similar analysis of the November, 1988-September, 1989 data base archived from the Florida LPATS network (owned and operated by ARSI) with very interesting results. Figure 6 shows a theoretical accuracy analysis of the Florida net, plus the receiver locations. The circle shows the location of the three towers illustrated in Figure 7. Figure 8 shows the plot of all strokes found within the general vicinity of the towers (located within the squares). Three fix groupings are highly obvious and are certainly strikes to the towers. Tower 1 had 36 strikes, tower 2 had 24 strikes, and tower 3 had 56 strikes. Figures 9 and 10 are blow-ups for better resolution, with a 200-meter x 200-meter grid superimposed. It is obvious that there is a southwest mean error of about 500 meters and a random error on the order of 200 meters or less (the average random error from the fix groupings centroid is much less). Comparing with Figure 6, we expect a random error of about 200-meters average. This is excellent confirmation of the analytical predictions and lends credibility to the random timing error figure used to produce the analytical results.

Careful examination of the 500-meter systematic offset error produced no obvious explanation. There were no significant errors in site coordinates (measured using GPS) and no error in the calculation of timing propagation offset correction factors. Further investigation finally revealed the source of the error to be primarily due to absence of provisions in the cen-

tral software to account for the fact that the earth is an oblate spheroid rather than a perfect sphere.

An oblate spheroid has a polar radius shorter than the equatorial radius; therefore, by using Helmert's iterative solutions for geodetic distances, it was found that the fixes moved 450 meters to the northeast if the earth's oblate characteristic was properly accounted for! This corrects 90 percent of the systematic offset error and renders it of less significance than the small random error. It is not likely that oblate corrections would render systematic errors less than the random error in the typical case. But, this example, based on real unprocessed data, effectively illustrates the inherent capability of the LPATS TOA system.

3.3 The Video Information System (VIS)

LPATS users do not need to purchase, maintain, or operate a lightning detection network. Rather, much in the manner of a dial-up radar service, users may subscribe to a data service provided by an operating network. At this time, the most commonly used device to acquire LPATS data is the Video Information System (VIS).

The VIS consists of a standard XT, AT, or a 386 personal computer with a minimum of one disk drive, enhanced graphics adaptor, monitor and keyboard (Figure 2). A VIS software package is loaded into the PC which provides the user with a visual workstation to observe the lightning within the area of interest and make decisions based on the data provided.

The lightning data displayed on the VIS equipment may be received by various means which include satellite broadcast, dial-up or dedicated telephone lines. Typical data receipt times vary according to the communications medium employed but normally no more than a 3 second delay between a stroke occurrence and data receipt can be expected. Figure 3 is a typical user station setup when lightning position data is received via satellite communications.

With systems installed throughout the U.S., national data is now available to any user who desires this large data base. However, smaller areas are available for those who's interest is limited to a local area. Figure 4 shows typical data areas available.

4.0 Types of Data and Their Effectiveness

When discussing this area, consideration must be given to the type of data, its timeliness, the manner in which it is displayed, and the ability of the end-user to manipulate and interpret the information. In addition, there must be some sensitivity given to the issue of alarms and the advantages and drawbacks of using such devices.

4.1 Types of Data

There are two types of data, realtime or aged data that represents lightning events that are or have taken place, and data that provides advance warning of the threat of lightning. Since timeliness will be discussed below, the focus at this point will be directed towards only the types of data and related pro and con issues.

4.1.1 Lightning Events

This data is frequently used to monitor the progress and/or progression of thunderstorm areas, both air mass and synoptic, respectively. The biggest advantage gained from this data is that the user can normally gain a better feel for the thunderstorm pattern and in most cases (if the software will support the effort) ascertain the trajectory and speed of the thunderstorm cell(s). The most critical drawback of such a system is that lightning must already be taking place.

While advanced systems are capable of displaying lightning occurrences in a matter of seconds after the event takes place, they cannot provide full protection from the first stroke emanating from a local air mass storm. While many may perceive this as an acceptable trade-off when considering the overall benefit gained from the entire system, people dealing with evolutions involving explosives and personnel safety issues cannot afford to treat such a risk as acceptable. To compensate for this weakness in is advisable to include some form of advance warning system within the lightning detection system configuration.

4.1.2 Lightning Potential Instrumentation

The most common technology utilized to detect potential for lighting strikes is that which is normally found in an electric field mill. In the past their has been some serious concern regarding the application of such systems since many view them as being prone to false alarms, and many production orientated people are hesitant to respond to an alarm that is initiated at a preset value that someone else claims is ideal to optimize system application.

In most cases, the field mill's reputation for false alarms is unfair since most of the time such determinations are based on observations obtained through application of non-scientific procedures. These procedures include the good old count the seconds between the lightning flash and the thunder to estimate the distance to the storm.

In all fairness, one must consider the fact that a realistic detection range for a field mill is normally less than five (5) miles, and at least 40% of the time, thunder associated with lightning is not heard by the people affected by it due to various atmospheric abnormalities such as sound focusing.

Recently, a comparison was conducted by ARSI whereby data from an electric field mill was compared directly with realtime lightning stroke data for the same location. As shown in Figure 11, the electric field mill was sensing the electric field in excess of 2,000 Vm at least five minutes prior to any lightning strike occurring within a 10 mile range (Point 1). In addition, the field mill shows at least 15 minutes of warning for a strike that occurred at a distance of less than 5 miles from the field mill site (Point 2). Of particular interest are the field changes that occur when lightning strokes take place nearby, as can be seen at points 1 and 2, and between points 3 and 4.

4.2 Timeliness of Data

There are only two categories of data that fall within this area, realtime and other than realtime. When viewing the application of the data within the explosives environment, it is obvious that realtime data, whether it be from a detection or warning system, is the only acceptable source of data that should be considered. The only value other than realtime data may offer is assistance during the investigation following a mishap. However, new software designs support archive and replay requirements.

4.3 Data Display

With the advent of high speed computers and enhanced video systems requirements for various capabilities within such media are numerous and varied. In general, there are two basic types, the Pavlovian Response and Graphic Map.

4.3.1 The Pavlovian Response

This basically entails a flashing lights, bells and whistles scenario that is designed to generate a response of sorts from the user. The most common display used is one that involves a pie shaped circle that will change color based on the number of flashes/strokes detected within a particular slice.

Some serious drawbacks from such a display include insensitivity to the storm's direction and speed, and the stage of development involved. In addition, many times such systems are advertised as providing the user with storm severity, which is normally determined by the number of strokes that occur within a given timeframe. This latter claim may be true in some cases; however, there is no scientific proof to support such a claim, and as stated earlier, lightning frequency is not a consideration with regard to storm severity.

The bigger drawback of such a display is the fact that the user never gets a feel for patterns associated with the storm, and is placed in a position that any action must be tied to the appearance of a color pattern and/or some form of alarm device, either audio and/or visual. This scenario creates problems that can impact on productivity and reduce user confidence. For example, many alarm events may later be ruled as false, and the user is forced into a position where they must wait for an alarm to occur before any action can be taken.

4.3.2 Graphic Map

Such a display provides an ideal picture of conditions to users since they can readily observe the storm's trajectory, lightning density, relative location and facilitate cell/area speed computation. In essence, the user is able to gain a "feel" for the storm(s) which can greatly assist in formulation of a decision as to whether a threat is present or not.

Through the use of various landmark features on the display the user can effectively apply the data to the other variables that are involved in making a decision as to what action should be taken to deal with the threat.

4.3.3 Data Manipulation

Most software packages are menu driven user friendly and include a basic screen display that is either generic to system users, or tailored to specifically meet both generic and unique needs. In addition, they will also include additional features that the operator can use to enhance and/or manipulate the displayed data. Some features that are common to most systems include zoom, time lapse and data looping.

Some of the more sophisticated user-friendly packages may include user programmable features that include alarm areas, movable windows, integration of field mill data, alternate map set-ups, range and bearing determination, predefined displays, and greater control of map and display features, titles and color coding. All of these elements further enhance the potential for accurate and effective interpretation by layman.

5.0 Integration With Heavy Weather Procedures

The key to optimizing the integration of data from lightning detection and warning systems is to identify; 1) vulnerable areas, 2) the level of intensity that will affect the particular area(s), 3) required action(s) and their impact on operations/productivity/safety, 4) communicating threat information; 5) personnel training, and 6) on-going program evaluation.

5.1 Identifying Vulnerable Areas

To adequately accomplish this element, all levels of the organization must evaluate the impact of lightning activity on their material facilities, standard operating procedures, personnel safety, and support facilities such as medical, recreational and security services. All elements within the organization's structure should be involved and individual assessments should not be assigned a priority or specific value at this point in time. In addition to routine issues, consideration should also be given to non-recurring activity such as construction work done by non-government contractors, open houses and sporting events.

Examples of areas to be addressed include the impact on power to critical systems such as EMCS transportation, inspection and handling of material, and public works evolutions and other facilities management related actions.

5.2 Level of Intensity Determination

The purpose of this phase is to establish the minimum threshold for each vulnerable element where conditions will produce injury, damage or an unacceptable environment. When determining a threshold value for any particular element it is important that you continue to treat each one as a separate entity and once again, refrain from assigning priorities. A good example of a result gained from such as evaluation would be the realization that it may be more important to monitor lightning near power lines that feed a computer center, rather than monitoring activity at the center itself.

5.3 Actions and Their Impact

One of the more difficult phases, it is important that while addressing the issues of action and impact, realistic approaches and honest evaluation prevail. At this point another element must be considered and that is for every action there will be a required response. The feasibility of executing the response and its initial acceptance by the responsible manager must also be an issue. This element will be critical in the future since it will impact directly on feedback during lessons learned reviews and improve the end user's overall perspective when dealing with an occasional false alarm.

While at this point one should still refrain from assigning priorities, it is important that flexibility be inserted within the individual actions and impact elements that are identified. This can be accomplished by listing in order, from the lowest to most severe, the actions that are required and the related impact on operations. In this way, analysis of the overall picture can result in a program containing flexibility factors that will limit to a major extent the impact on productivity and time-management without compromising the goal of the action.

Example:

Take for instance a fuel farm that is very active during the daytime and is closed after normal working hours. The minimum action identified for the facility is that personnel are notified in advance that based on local forecasts, thunderstorms can be expected in the area during the next six (6) hours, but based on existing data, none are expected within the next hour. Based on an initial condition of readiness (lowest), the only impact on operations would be for personnel to review what actions they will be required to take should the next level of readiness be issued.

The next level of readiness might inform the facility that data patterns indicate they can expect a lightning hazard within the hour. This action should induce a response that would include actions such as stowing loose articles, securing sensitive equipment that is not being used, review of any planned evolutions that could be restricted by the phenomena, and review of actions that should be taken should a warning be issued and which personnel will be responsible for executing the actions. As you can see at this point, the impact is still kept at a minimum.

When the data indicates that the highest level of readiness must be implemented, then such an action should be identified as a "WARNING". In this case, lets say the "WARNING" calls for lightning within 15 minutes (we'll assume the storm is within 10 miles), and the required action is to secure operations, have personnel seek shelter, take other systems off-line that could be affected, and notify responsible authority that actions are complete. At this point the impact is at its greatest in that the facility was functional to the maximum allowable until there was no choice but to shut down. However, as you can readily see, the overall impact on the fuel farm's mission was significantly reduced, which is a result of the flexibility factor.

At this point, it should be noted that another critical element that is needed to effectively analyze the impact on a particular mission area is to conduct a periodic review of lessons learned and modify the basic plan as needbe. This element is discussed later in this section.

5.4 Program Set-Up

When every area has been evaluated and the actions and their impact identified, it is time to analyze the data and assign priorities. These priorities should fit into one of the following categories; 1) Major (work stoppage/extreme danger/severe damage), 2) Moderate (reduced operations/little or no safety issues/minimum potential for damage, and 3) Minor (generally no impact of any consequence.

In setting-up the implementing procedures it is advisable to use a sequence of numbered "conditions of readiness" (COR) to mark the advent of the threat, and only apply the title of "WARNING" when the threat is real and actions of the highest impact are required. Experience has shown that development of sub-conditions of readiness (i.e. 1A, 1B, etc.,) tend to cause confusion in the long run.

When issuing CORs or warnings it is important to identify a time-frame for which the action is valid. As a minimum this time-frame should span at least one hour. In addition, where feasible, setting of CORs should be done in advance of the start point of the effective period. While extensions of CORs and warnings should be permitted, this type of action should be limited to two. Once two extensions have been used, then the issuing authority should be required to reevaluate the situation and issue a new COR or warning. The new action should go into effect at the termination time of the last extension.

Example:

*At 1005, conditions indicate that a COR must be issued to provide a low grade alert to activities regarding the anticipated development of thunderstorms during the early afternoon. The following COR is typical of what should be promulgated to supported activities:

Set Thunderstorm Condition II effective from 1030 to 1630 local time.

Narrative: Patterns indicate that thunderstorm activity, accompanied by strong winds and lightning is expected within the next six hours, but not within the hour.

*At 1340 a review of the situation indicates that the storms are developing as forecast and data shows that the movement of the cells is such that they will affect all or part of the facility within the hour and patterns indicate that the activity could last for a few hours.

Set Thunderstorm Condition I effective from 1400 to 1600 local time.

Narrative: Present conditions indicate thunderstorms, accompanied by strong winds and lightning, can be expected within the hour.

*At 1430 the thunderstorm patterns are approaching the maximum acceptable range where action of the highest nature must be implemented. A statement is included within the Condition I procedures which tells people they must be ready to implement "WARNING" related actions on short notice. Therefore, for record purposes, the warning base time will be the time at which the first notification action is taken, and the effective time for people notified will be the time of notification. It is also determined that conditions will last for approximately 1 1/2 hours.

Set Thunderstorm Warning effective upon receipt until 1600 local time.

Narrative: Thunderstorms, accompanied by strong winds and lightning, are eminent.

5.5 Communicating the Threat

The most critical element, it is essential that methods used to implement warnings/CORs utilize the fastest means possible, be reliable, and involve a medium that permits clear and concise transfer of information and guidance. In addition, it is equally important that an alternate or duel medium be identified. An example would to use an auto-dial phone system as the prime method and as a back-up, sound an audible alarm to alert the people involved. Some locations, such as NAS Pensacola, utilize a paging (beeper) system as a prime means of passing an alert, while other activities use them as a back-up..

Another element regarding communications is to keep to a minimum, the number of personnel to be contacted by the responsible authority. Notification of units that have no critical need for immediate notification should be left to a higher level within their organization. For example, it is more realistic to call recreational services and pass the word about lightning so they can notify the pools, golf courses, and other facilities under their control. On the other hand, it would be more realistic to directly contact the

fuel farm then to pass the data via another office since a delay could have a serious impact.

In addition, the information passed should be kept to a minimum and only relate to the issue. This will reduce potential for confusion. A call sheet should be developed for each phenomena (i.e. thunderstorms, high winds, etc.,) and the activities listed should be listed an order of priority that is relative to the phenomena. For example, while the fuel farm may be high on the thunderstorm list, it would be at a lower level on the high winds list.

5.6 Personnel Training

There should be three separate levels of training; 1) evaluation of data and the subsequent setting of CORs and warnings, 2) data dissemination, and, 3) execution of procedures and subsequent reporting of readiness attainment.

People tasked with making the final decision to set a COR or warning must have adequate knowledge of the phenomena involved to qualify their actions and in some cases actually conduct the evaluation of data. Therefore, training for these individuals should be tailored to the minimum requirements necessary to perform the action, and include pre-seasonal reviews of typical weather patterns and related CORs and warnings, and require an annual re-certification.

It should be noted that in most cases, even at locations where a weather office is located, the weather activity can only recommend an action. The overall responsibility and authority to set a COR or warning still rests with the senior official in charge of the host activity. At best, personnel from the weather office should be utilized to train the people who will authorize the setting of the COR or warning.

Personnel involved with the dissemination or receipt of the COR and warning data must have a basic understanding of the types of CORs and warnings and the related phenomena. In addition, they must also be intimately aware of the importance of record keeping and their responsibility, if applicable, to pass the data, in a timely and concise manner, to others within their organization. In most cases, an effective pre-qualification program and the in-house training program will readily meet the need.

When viewing the issues of taking action and reporting attainment of a readiness level, it is obvious that training regarding such items should be an integral part of the in-house training program and listed occasionally within documents such as a plan of the day or safety notice.

5.7 On-going Program Evaluation

Such a program is the most critical element in any weather related COR/warning related program. For the most part one can anticipate that at least 80% of the initial program will adequately satisfy overall needs and goals and that some adjustments will be required within the remaining areas of the plan.

It is important that when implementing the initial plan a moratorium of 3 to 6 months be put into place that restricts changes to the plan unless they are critical in nature and correct documented deficiencies that cannot be tolerated for the duration of the period. This limitation will provide users with an opportunity to live with the system and therefore force them to work with what they have for a while. The long term gain from such a policy will be that for the most part, changes that are recommended after the moratorium will normally include an adequate level of supporting documentation, and lack emotion.

Another sound forum that will improve the effectiveness of the plan is the conduct of Lessons-Learned Meetings during which new ideas, mistakes made and new requirements driven by mission change(s) are actively discussed. The results of such gatherings can significantly reduce the administrative cost and manhours expended in the preparation, evaluation and implementation of changes/updates to the basic plan.

6.0 Conclusion

While the information and ideas expressed above may not provide a solution to a specific problem, they do provide an initial point from which an effective program can be developed which will adequately solve most of the day-to-day problems that consume enormous amounts of time and money.

The key point is that by better understanding the phenomena and its impact, and dealing with it head-on through use of adequate equipment and a flexible plan, a significant improvement in your overall operation and the safety environment of your personnel can be realized.

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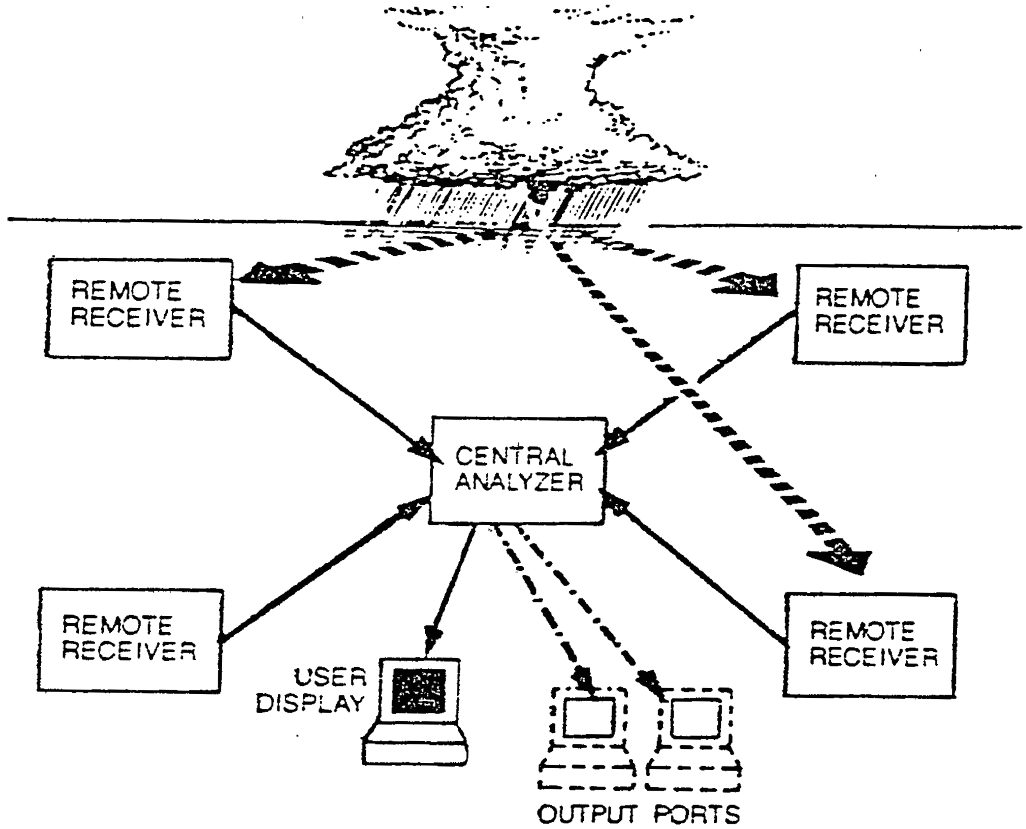


Figure 1

The LPATS system consists of three or four remote receivers that monitor lightning stroke characteristics over a wideband frequency range. Each receiver obtains the data from a small vertical antenna. Waveform analysis is performed in the receiver, and pertinent information is passed over the telephone or microwave links to a central analyzer. The central analyzer then computes the strike location. This information is time tagged and made available to several output ports for communication to a monitor.

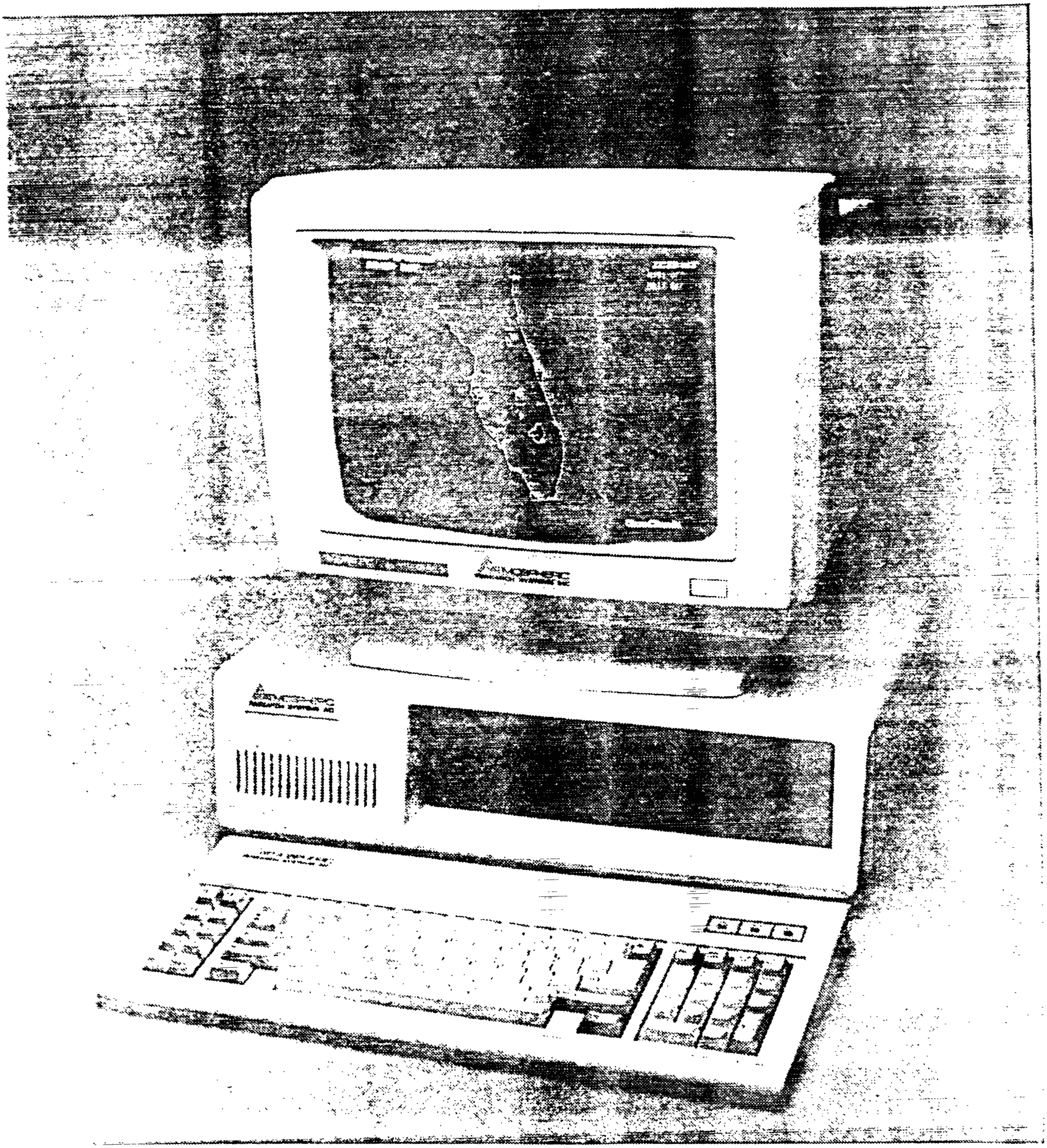


FIGURE 2

VIDEO INFORMATION SYSTEM HARDWARE

LPATS NATIONAL NETWORK (LN^2)

LPATS Data System Structure

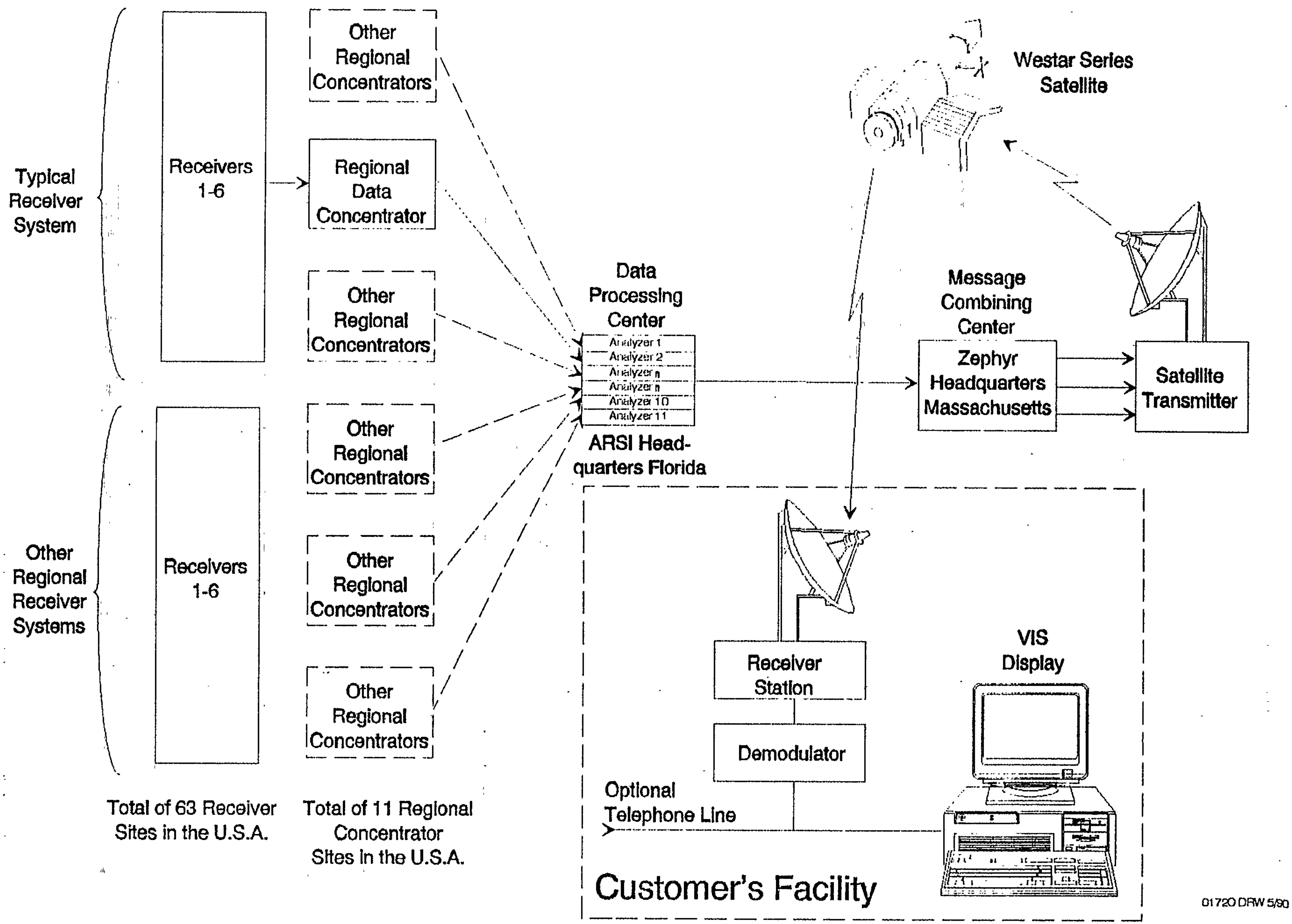
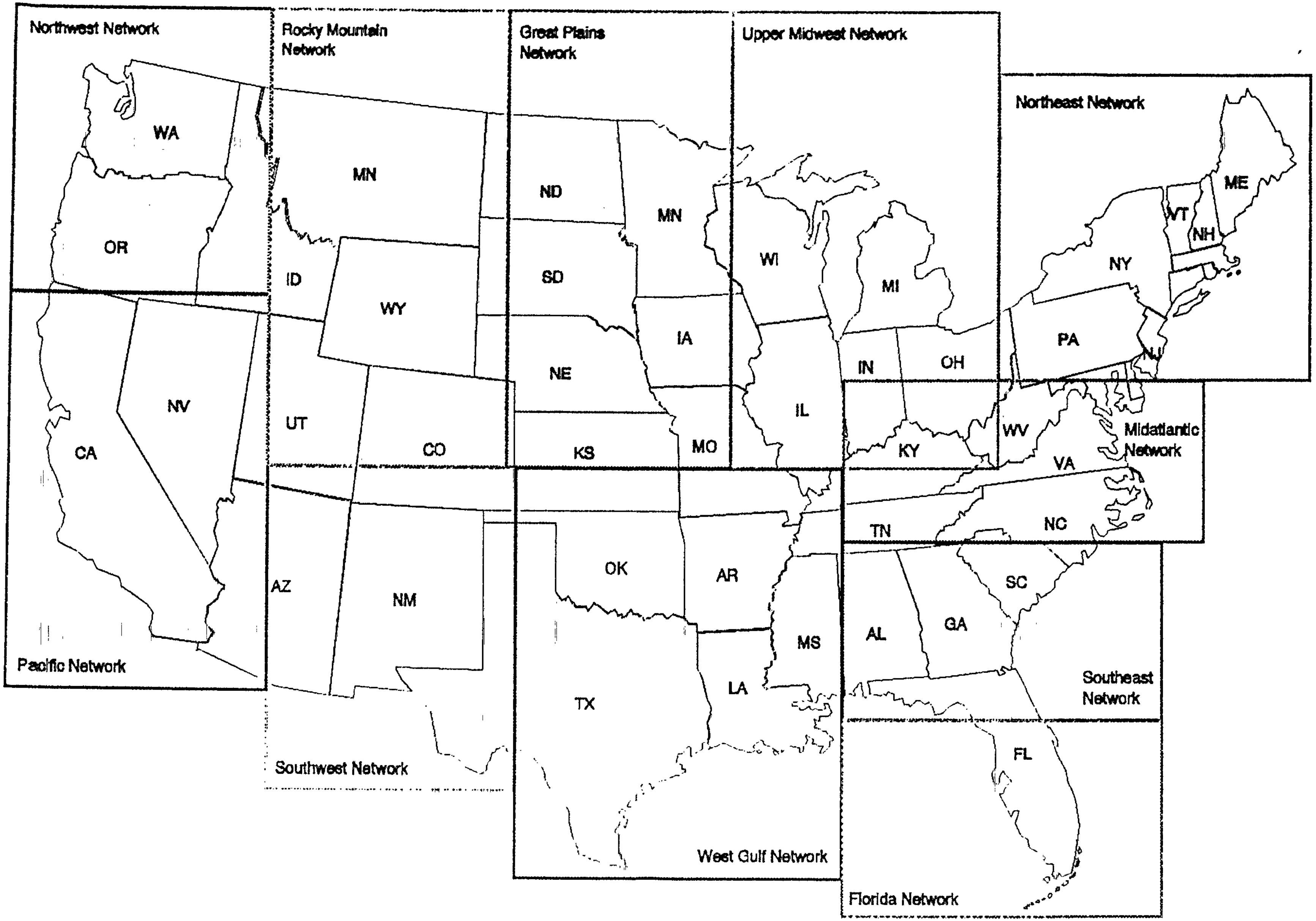


FIGURE 3



LPATS National System: Regions

FIGURE 4

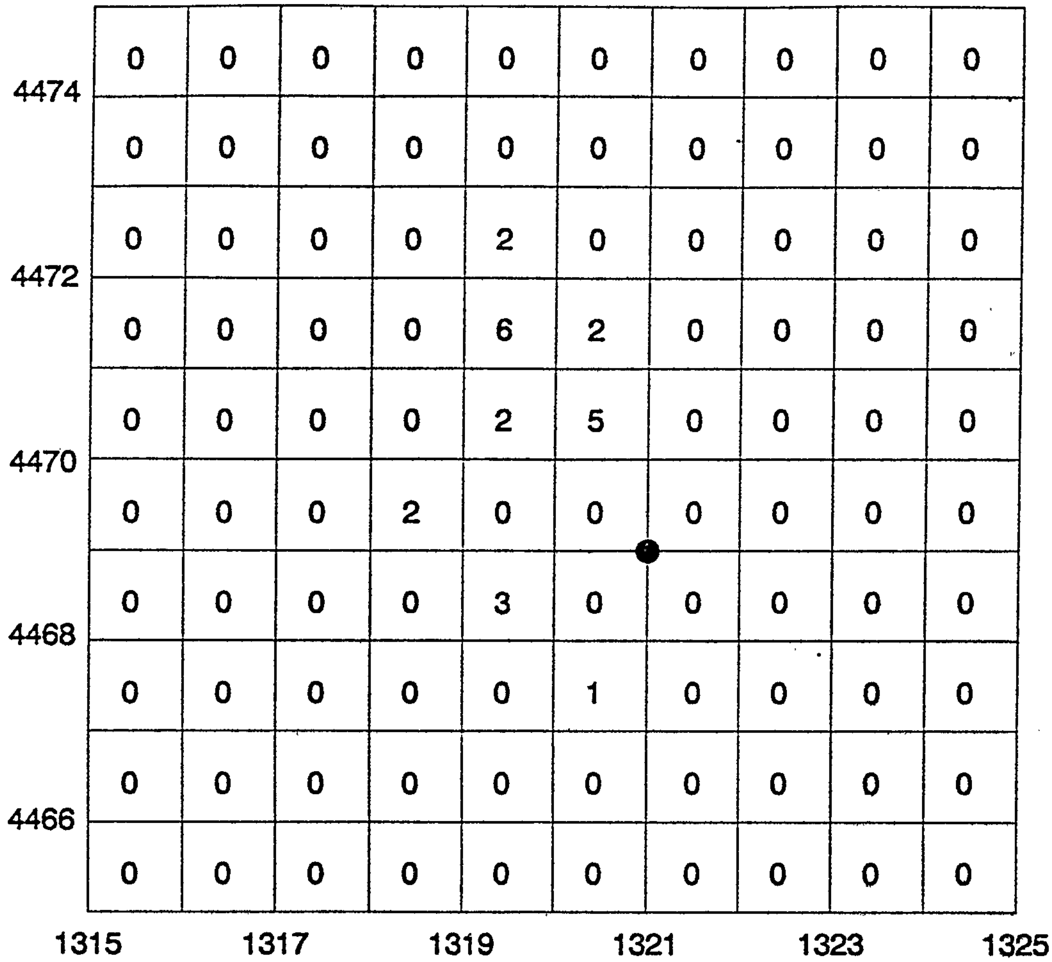


FIGURE 5

Recorded strokes in 1988 around a 300 m high TV-transmission tower. The number of strokes in each cell has been given (cell size is 100 m * 100 m).

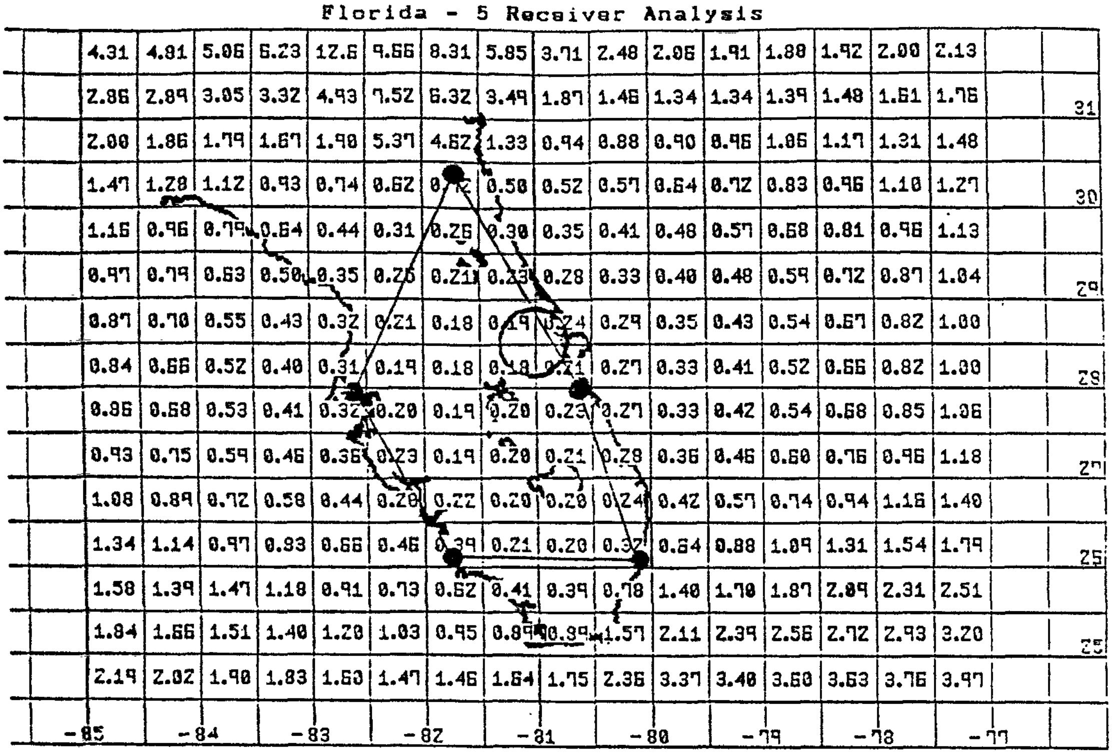
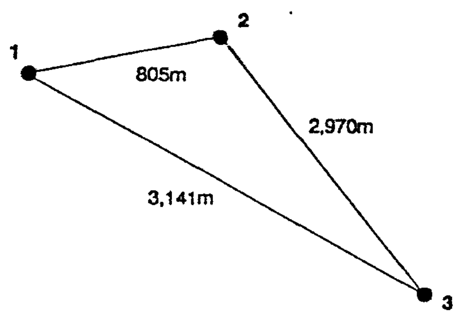


FIGURE 6

LPATS ACTUAL PERFORMANCE

Lightning Strikes to Three Radio/TV Towers at Bithlo (near Orlando, Florida U.S.A.)



TOWER NO.	LATITUDE	LONGITUDE	HEIGHT
1	28.6022°	81.0937°	1,800 ft. (549m)
2	28.6047°	81.0869°	1,420 ft. (433m)
3	28.5805°	81.0756°	1,609 ft. (490m)

FIGURE 7

Bithlo Tower Data

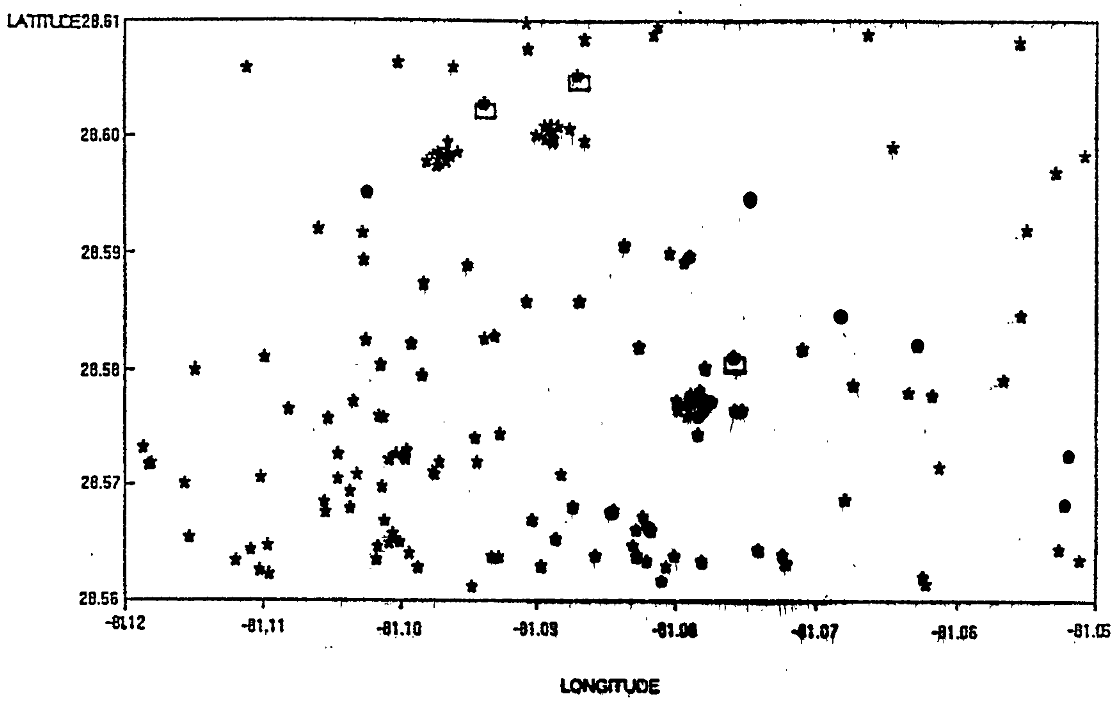


FIGURE 8

LPATS ACCURACY DATA

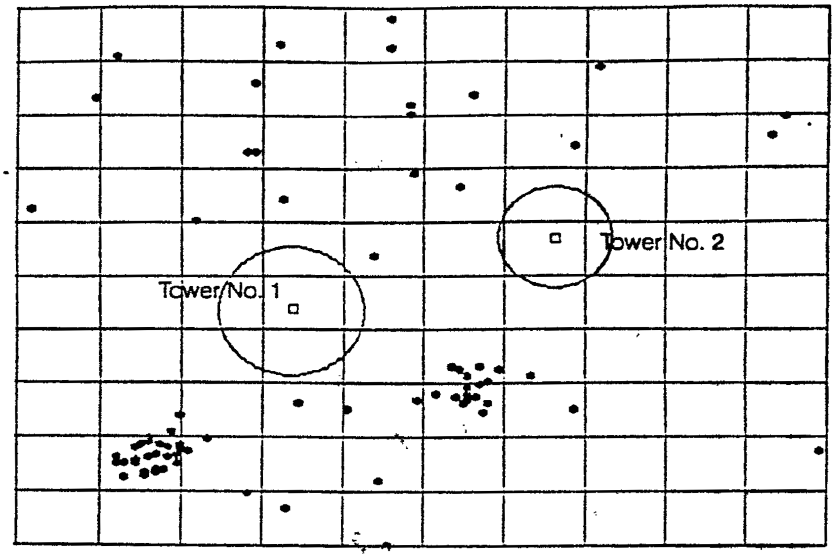


FIGURE 9

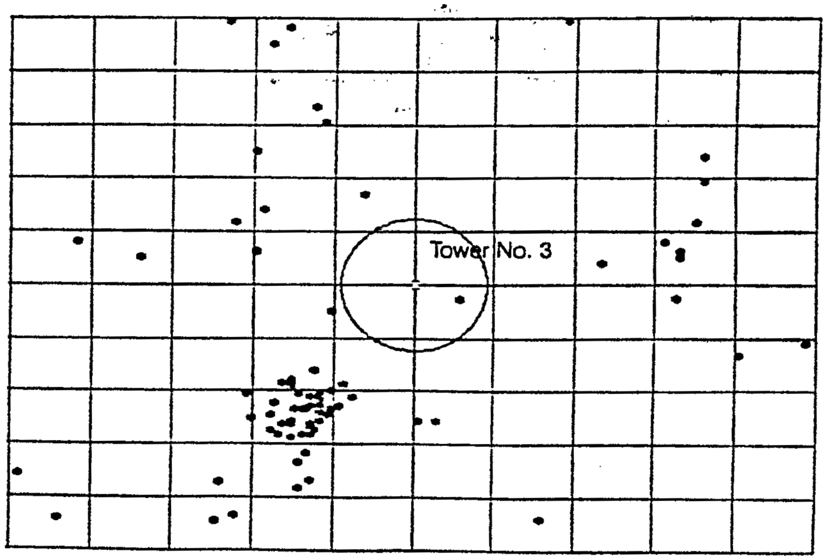


FIGURE 10

Grid size: 2 km x 2 km

Cell size: 200m x 200m

TYPICAL ELECTRIC FIELD MILL DATA
DURING LIGHTNING ACTIVITY

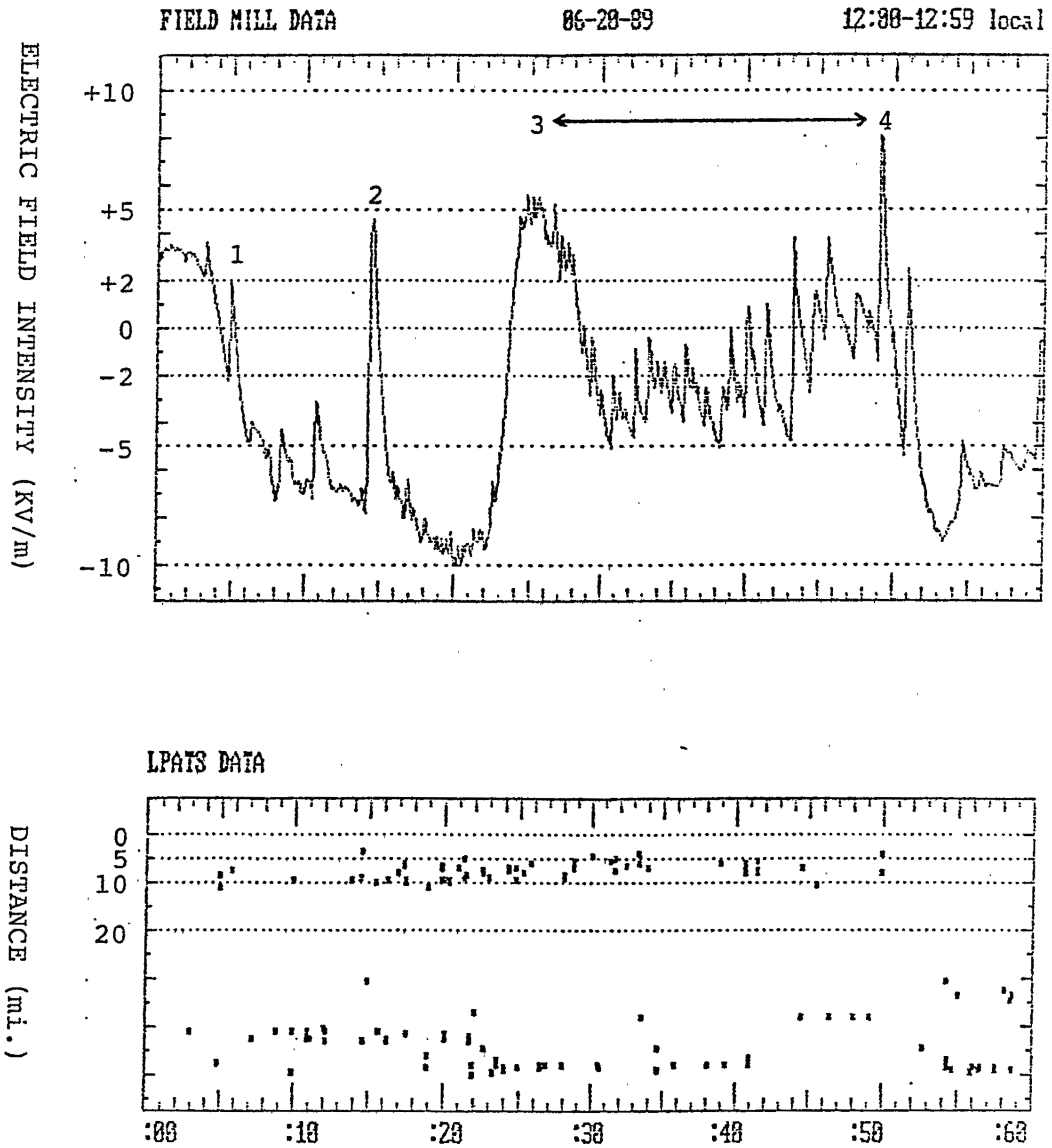


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FIGURE 11